Grit-Use Behavior in Birds: A Review of Research to Develop Safer Granular Pesticides

Louis B. Best, Department of Animal Ecology, 124 Science II, Iowa State University, Ames, IA 50011

ABSTRACT

Understanding avian grit-use behavior and the physical characteristics of grit particles that influence their consumption by birds can aid in formulating safer granular pesticides. Potential routes of avian exposure to granular pesticides include birds perceiving the granules as a source of grit and picking them up intentionally. Pesticides formulated on granules are used extensively in agricultural production, and many are highly toxic to birds. Despite this, past formulation decisions have not included assessments of avian risks. A research program was initiated that included several phases of investigation. Natural grit-use patterns (the occurrence and amount of grit in gizzards, characteristics of individual grit particles) were evaluated for 22 bird species that commonly use cornfields when granular pesticides are applied. Experiments also were conducted with house sparrows *(Passer domesticus)* and northern bobwhite *(Colinus virginianus)* under controlled aviary/laboratory conditions to elucidate the effects of grit size, shape and surface texture, and color on grit use. Birds consuming small grit had >5 times more particles in their gizzards than birds consuming large grit, and birds preferred angular/oblong grit over rounded/spherical grit. Yellow, green, and white grit was consumed most, whereas very little black and blue grit was used. Birds strongly preferred silica granules and were least likely to consume those made of gypsum or corncob. We also found that most grit is rapidly replaced in gizzards, usually within 5 days of ingestion, and that the integrity of granular pesticide carriers in gizzards differs greatly. Relative avian risks associated with various experimental granular pesticide formulations were assessed. Variables evaluated included pesticide concentration per granule, granule carrier type, and granule size and color. This review of recent research shows several factors that influence the potential for avian exposure to granular pesticides and how such factors can be used alone, or in combination, to reduce avian risks. Studies with other species and under different test conditions are needed to determine the general applicability of these results.

KEY WORDS

birds, granular pesticides, grit use, research protocol

INTRODUCTION

Granular pesticides are used extensively throughout the United States to control agricultural crop pests (U.S. Environmental Protection Agency 1992). Granular formulations are often preferred over liquid formulations because they are safer and easier for the applicator to use and because they are more effective in controlling certain pests. Granular formulations development has focused on maximizing effectiveness for pest control but has largely ignored avian risks. Many granular pesticide formulations are highly toxic to birds (Balcomb et al. 1984, Hill and Camardese 1984), and bird mortality has resulted from their use (U.S. Environmental Protection Agency 1985, 1989, 1992). This mortality has prompted the need to explore means of reducing the risk of adverse effects in birds.

There are several means by which birds may be exposed to granular pesticides, but of particular concern is the possibility that birds may ingest the granules either inadvertently or intentionally. Various means are used to bury the granules below the soil surface during application, but some particles are left uncovered (Erbach and Tollefson 1991). The focus of our research (and this review) is pesticide exposure via the birds perceiving and ingesting granules as a source of grit.

Granular pesticide formulations differ in many respects, including granule size, shape and surface texture, composition, color, and pesticide concentration per particle. Until recently, how each of these characteristics affected the risk of avian exposure was largely unknown, and such factors were not accounted for in the U.S. Environmental Protection Agency's risk assessment of granular pesticides (U.S. Environmental Protection Agency 1992). We felt that there was a need to better understand avian grit-use behavior and how the physical characteristics of grit particles influence their consumption by birds. This information could aid in assessing avian risks associated with granular pesticide use and in formulating safer products. We conducted a multiphased research program with birds that included (1) characterizations of natural grit-use patterns, (2) evaluations of the effects of physical characteristics of grit on grit ingestion, (3) evaluations of preferential consumption of various granule carrier types, (4) measurements of grit retention and granule integrity in gizzards, and (5) actual assessments of avian risk associated with several experimental granular pesticide formulations.

CHARACTERIZATIONS OF NATURAL GRIT-USE PATTERNS

Although many crops are treated with granular pesticides in the United States, the greatest use is for the control of corn pests (U.S. Environmental Protection Agency 1992). Thus, we focused our initial characterizations of grit-use patterns on 22 bird species that commonly use cornfields during the breeding season (Best et al. 1990) when most granular pesticides are applied.

In our study (Best and Gionfriddo 1991*a*) grit use was characterized by recording the frequency of occurrence and amount of grit in gizzards and by measuring the size, shape, and surface texture of individual grit particles. If the characteristics of grit naturally selected by the birds were known, then we could compare those characteristics with the characteristics of various pesticide granules to determine the degree of similarity, and thus the potential for birds to

mistakenly ingest the granules as grit. The longest and shortest dimensions of each grit particle were measured and then averaged to get a measurement of grit size. A shape index value was calculated for each grit particle by dividing the longest dimension by the shortest dimension. A value of 1.0 represented a spherical shape, and larger values represented progressively more oblong shapes. Grit surface texture also was classified into five categories: angular, subangular, subrounded, rounded, and well rounded.

The frequency of occurrence of grit in gizzards (i.e., the proportion of gizzards with grit) and the amount of grit in gizzards differed greatly among bird species. These measures reflected the birds' propensities to consume grit and, potentially, to consume pesticide granules as grit. Frequencies of occurrence ranged from 15% for the dickcissel *(Spiza americana)* to 100% for the ring-necked pheasant *(Phasianus colchicus)* and Savannah sparrow *(Passerculus sandwichensis)*. The amount of grit in gizzards also differed greatly among species, with median counts per gizzard ranging from 0 to 69. As expected, the species with the lowest proportions of gizzards with grit also had the lowest grit counts per gizzard. The amount of grit in gizzards of individuals of the same species also was highly variable. For example, the median grit count per gizzard for the American crow *(Corvus brachyrhynchos)* was 2, yet individual grit counts ranged from 0 to 234.

The grit sizes found in bird gizzards were related to body size; mean grit size increased linearly with the $\log_{10}$ of the body mass. Mean grit sizes of individual bird species ranged from 0.6 mm for the brown-headed cowbird *(Molothrus ater)*, American robin *(Turdus migratorius)*, and red-headed woodpecker *(Melanerpes erythrocephalus)* to 3.4 mm for the American crow. The distribution of grit sizes used by individual species differed greatly; for example, American robins used a narrow range of grit sizes, whereas ring-necked pheasants used a broad range. The grit-size distribution profiles of most species had definite peaks, with grit use declining noticeably on either side of the preferred grit size. Birds that used larger grit sizes also were more variable in their selection of grit size.

The grit shapes selected by cornfield birds differed considerably, ranging from nearly spherical (e.g., American crow; mean shape index = 1.5) to more oblong (e.g., common grackle [*Quiscalus quiscula*]; 3.0). Species more specialized in their selection of grit shapes tended to use more spherical grit, whereas those using disproportionately more oblong grit were more generalized in their choice of grit shapes. Surface textures of grit found in gizzards ranged from particles with sharp, irregular corners to those with very rounded surfaces devoid of irregularities; however, most grit particles had intermediate surface textures. Of the species studied, the European starling *(Sturnus vulgaris)* had the highest proportion of angular-shaped grit in its gizzards, and the ring-necked pheasant had the greatest proportion of rounded, smooth-surfaced grit.

There are limitations to evaluating gizzard contents and equating those results to grit use. This is because the grit in gizzards reflects not only preferences of the birds but also is influenced by availability and grit retention in the gizzard. Despite its limitations, our study was the first attempt of its kind to provide important baseline data that could be used to develop safer granular pesticide formulations.

EFFECTS OF PHYSICAL CHARACTERISTICS ON GRIT USE

The second phase in our research was to evaluate bird preferences for grit size, shape and surface texture, and color under controlled aviary/laboratory conditions. The house sparrow and northern bobwhite were used because they are ground foragers (De Graaf et al. 1985) and represent the feeding guild of birds most susceptible to soil-applied granular pesticide formulations. The house sparrow also was chosen because it uses a large amount of grit compared with other birds (Best and Gionfriddo 1991*a*). These two species also provided a good contrast in that they represented two different avian orders, differed in body mass by a factor of six (Dunning 1993), and differed in previous experience (wild-caught versus captive-reared). Details of the methods and results of this phase of our research can be found in Best and Gionfriddo (1994*a*) and Gionfriddo and Best (1995, 1996).

Grit Size Experiment

To evaluate the effects of grit size on grit consumption, house sparrows were given an ad libitum supply of either small (0.2–0.4 mm) or large (1.0–1.4 mm) grit. These sizes represent the lower and upper ends of the normal range of grit sizes used by free-ranging house sparrows. The mean grit count per gizzard of sparrows consuming small grit was more than five times that of birds consuming large grit, but the mean volume of grit per gizzard was calculated to be eight times greater for the birds consuming the large grit. Thus grit consumption (and possibly retention) was influenced by grit size.

Grit Surface Texture and Shape Experiments

The effects of surface texture and shape on grit selection were evaluated by using house sparrows and northern bobwhite. The birds were given a mixture of equal volumes of two grit types, representing two extremes in surface texture/shape: angular/oblong and rounded/spherical. The grit supplied to the sparrows was composed of quartz; that provided to the bobwhite was glass. For each species, the two grit types were identical in mineral composition, color (clear), and size. At the end of the experimental period, most birds (24 of 30 sparrows and 21 of 26 bobwhite) had significantly more angular/oblong than rounded/spherical grit in their gizzards, showing that both species expressed a similar preference for grit surface texture/shape.

Grit Color Experiments

Color preferences have been documented in experimental studies of avian feeding behavior (e.g., Hailman 1966, Brunner and Coman 1983, Roper and Cook 1989), and color may be an important factor influencing avian consumption of grit or granular pesticide formulations. Grit (granule) color choice in birds may be influenced by innate or learned preferences or aversions for specific colors and/or by the relative conspicuousness of various colors against a soil background.

In our experiments, house sparrows and northern bobwhites were offered glass grit consisting of a mixture of equal amounts of eight colors (red, brown, yellow, green, blue, black, white, clear). The grit was scattered in trays on either a light-brown or dark-brown soil background. Both species were consistently nonrandom in their consumption of colored grit, and most individual birds focused their grit consumption on particles of one or a few colors. Although the "favored" color(s) varied among individual birds, some grit colors were preferred by more birds than others. Yellow, green, and white were consumed most by both species; very little black and blue grit was ingested. Soil background had only a slight influence on grit color selection, and only with house sparrows.

PREFERENTIAL CONSUMPTION OF GRANULAR PESTICIDE CARRIERS

The third phase of our research assessed preferential consumption by house sparrows of various carriers used to formulate granular pesticides (Best and Gionfriddo 1994*b*). The sparrows were given a choice between silica granules and one of five other granule carrier types. The alternative carrier types selected represented a sample of the granule types being used in granular pesticide formulations and included a heat-treated montmorillonite clay, a bentonite form of montmorillonite clay, gypsum coated with graphite, corncob, and a cellulose complex. Silica granules were used for comparison because they are composed of quartz, a material that birds normally consume for grit. In addition to composition, these carrier types differed in size, shape, surface texture, and color. It was felt that the differences in the characteristics of these carriers would influence their attractiveness to birds and thus the potential for their consumption.

These experiments clearly demonstrated that the physical characteristics of granular pesticide formulations influence their use by birds. House sparrows strongly preferred silica granules over the alternative carrier types when measured by trips to the granule trays and pecks/trip. The percentage of the total trips to the trays containing the silica was $>68\%$ in every choice test. The percentage of the total pecks that occurred in the trays with silica exceeded 92% in all tests. Of the five alternative carrier types tested, the sparrows consumed those made of clay the most and those made of corncob and, especially, gypsum the least.

GRIT RETENTION AND GRANULE INTEGRITY

The amount of grit used by birds depends not only upon grit availability and preferences, but also on grit retention once the particles are ingested. The passage rates of grit through the gastrointestinal tracts of birds influence the dynamics of grit consumption. We evaluated grit retention rates in gizzards by giving house sparrows access to quartz grit for at least 2 weeks and then shifting the birds to feldspar grit (Gionfriddo and Best 1995). Particles of the two mineral types were similar in physical characteristics and could only be distinguished under a microscope. The rates of replacement in gizzards of the first grit type by the second were determined by examining gizzard contents at various time intervals after the shift.

Most of the grit (>80%) in sparrow gizzards was replaced rapidly, usually within 5 days of ingestion. Replacement of the remaining grit, however, proceeded much more slowly. Furthermore, gizzards of birds given only small grit retained grit longer and contained more particles than those of birds given only large grit. Other related work involved dosing (via oral gavage) wild-caught house sparrows and red-winged blackbirds *(Agelaius phoeniceus)* with untreated silica granules, releasing the birds, and then determining the number of granules remaining in their gizzards at various time periods afterward (Fischer and Best 1995). As with the quartz and feldspar study, elimination of the granules from the gizzard was initially fast and then very slow.

Other studies assessed the integrity (i.e., durability) of six granular pesticide carriers in house sparrow gizzards (Best and Gionfriddo 1991*b*, 1995). The sparrows were gavaged with a gelatin capsule containing 20 granules of the carrier type being tested. Birds were sacrificed at six time intervals after the capsules were administered, and the granules or granule fragments were counted in each gizzard. Granules made of bentonite clay, gypsum, and cellulose complex disintegrated very rapidly in gizzards (within 1 hr); heat-treated clay and corncob particles were retained in gizzards for several hours; and silica was the most persistent.

Granules that break down rapidly cannot function as grit in the gizzard and would not provide the same sensory cues as those of natural grit. Thus, if a bird mistakenly picked up granules that break down rapidly in response to some internal stimulus to consume grit, that "appetite" would not be satisfied, and the bird might continue to consume additional granules. Thus granule integrity could influence consumption rates. This would be most likely for pesticides of low toxicity or where the pesticide concentration per granule was low.

RISK ASSESSMENTS WITH EXPERIMENTAL FORMULATIONS

Having gained some understanding of avian grit-use patterns and bird responses to various grit/granule characteristics, we have now proceeded to evaluate relative avian risks associated with various experimental formulations of granular pesticides. Knowledge gained from previous studies was used to determine the test formulations to be evaluated. An organophosphorus pesticide acutely toxic to birds (fensulfothion) was formulated on granules to evaluate the effects of carrier type, pesticide concentration per granule, granule size, and granule color on avian risk (Stafford, et al. 1996; Stafford and Best, unpubl. data). The carrier types selected were silica, heat-treated clay, and corncob. Pesticide concentrations per granule represented 1/2, 1/8, and 1/32 of the LD_{50} and influenced how many granules a bird would have to consume to be poisoned. The two sizes represented the upper and lower size range of grit normally consumed by house sparrows. The two colors used were white and blue; white was one of three colors favored by birds; and blue, one of two colors avoided (Gionfriddo and Best 1996).

The experiments were conducted on simulated soil surfaces, and the pesticide was applied in bands similar to normal row-crop field operations. Exposure was evaluated by documenting mortality, behavioral symptoms of organophosphorus intoxication, and blood plasma and brain cholinesterase activity. The findings suggest that the carrier type and pesticide concentration per

granule do influence avian risk. Weather and food availability also may play an important role in the dynamics of exposure to granular pesticides.

CONCLUDING COMMENTS

The U.S. Environmental Protection Agency uses only acute oral toxicity data and estimates of the number of granules exposed on the soil surface in determining comparative avian risks from granular pesticide formulations (U.S. Environmental Protection Agency 1992). Although the probability that birds will encounter granules is, indeed, a function of the number of granules exposed per unit area, the likelihood that birds will consume any of these granules is a far more complex issue. Our research has demonstrated several factors that may influence the potential for avian exposure to granular pesticide formulations.

Our studies of grit and granule choice in birds have been restricted to two species and to one experimental design (i.e., birds housed in aviaries, grit/granules presented in trays, etc.). Results produced under other experimental conditions could differ. For example, the amounts and characteristics of grit/granules used by birds can be influenced by diet (e.g., Norris et al. 1975, Alonso 1985, Norman and Brown 1985, Hogstad 1988, Gionfriddo and Best 1995) and by environmental conditions (e.g., Best and Gionfriddo 1994; Best et al. 1996). Research is needed with additional avian species and under different test conditions to provide a thorough understanding of avian grit/granule preferences and of the influences of particle characteristics on choice and retention by birds. The consistency of bird responses to various grit/granule characteristics will determine the degree of reliance that can be placed on such factors to reduce avian risks from granular pesticide formulations.

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